



Assessment of the recurrence interval of wildfires in mainland Portugal and the identification of affected LUC patterns

Bruno M. Meneses, Eusébio Reis & Rui Reis

To cite this article: Bruno M. Meneses, Eusébio Reis & Rui Reis (2018) Assessment of the recurrence interval of wildfires in mainland Portugal and the identification of affected LUC patterns, Journal of Maps, 14:2, 282-292, DOI: [10.1080/17445647.2018.1454351](https://doi.org/10.1080/17445647.2018.1454351)

To link to this article: <https://doi.org/10.1080/17445647.2018.1454351>



© 2018 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group on behalf of Journal of Maps



[View supplementary material](#)



Published online: 22 Apr 2018.



[Submit your article to this journal](#)



Article views: 541



[View Crossmark data](#)



Citing articles: 2 [View citing articles](#)



Assessment of the recurrence interval of wildfires in mainland Portugal and the identification of affected LUC patterns

Bruno M. Meneses ^a, Eusébio Reis ^a and Rui Reis ^b

^aCentre for Geographical Studies, Institute of Geography and Spatial Planning, Universidade de Lisboa, Lisboa, Portugal; ^bGeneral Directorate for Territorial Development, Lisboa, Portugal

ABSTRACT

Wildfires are responsible for major land use and land cover (LUC) changes. These events are frequent and catastrophic in Portugal and are responsible for great damage and loss of human life. In this study, a map to assess the probability of wildfire occurrence (PWO) in mainland Portugal was created for the period 1975–2017 (first half of 2017). The PWO was obtained by the superimposition of all layers by adding all the burned areas for the total period. It was observed that the occurrences and extent of the burned areas are highly variable from year to year. The PWO map was cross-referenced with LUC geoinformation to evaluate the LUC types that were more affected by the wildfires. The results presented and the PWO maps are important for the management and planning of forest areas and for the creation of guidelines to implement preventive and reactive actions in case of wildfires.

ARTICLE HISTORY

Received 3 October 2017
Revised 7 March 2018
Accepted 11 March 2018

KEYWORDS

Wildfires; occurrence probability; return interval; LUC patterns; mainland Portugal

1. Introduction

The Mediterranean region has a long history of fires, and these events have been an important factor in forestry, agriculture, and grazing (Ferreira-Leite, Bento-Gonçalves, Vieira, Nunes, & Lourenço, 2016). However, the wildfires have devastated the Portuguese forest and small villages, with large consequences at different levels: social, economic, and environmental (Pereira, Pereira, Rego, Silva, & Silva, 2006).

The land use and land cover (LUC) of Portugal suffered large changes in recent years (Meneses, Reis, Pereira, Vale, & Reis, 2017; Pôças, Cunha, & Pereira, 2011; Santos, Tenedório, Rocha, & Encarnação, 2005), and these changes are explained largely by the occurrence of wildfires (Maia, Pausas, Vasques, & Keizer, 2012; Oliveira, Pereira, & Carreiras, 2012). The climate of Portugal promotes the occurrence of wildfires, as it has a rainy season during the spring, which is favorable to the development of vegetation, followed by a very warm period that triggers the development of large wildfires (Gomes, 2006) (on the coastline of Portugal, from north to south, the average temperature varies between 20.5°C and 23.6°C, the northwest of this country and a part of center sector varies between 19°C and 21°C, and areas to the south vary between 22°C and 24°C). The different types of climate create the conditions for the existence of different fire regimes in this territory (Parente, Pereira, & Tonini, 2016).

Several causes have been identified for the occurrence and development of large wildfires in Portugal: one is the increase in area covered by eucalyptus trees (Maia et al., 2012; Oliveira et al., 2012), and others are the increase in abandoned farmlands (Ferreira-Leite et al., 2016) and the reduction in pasturing (increasing the availability of fuel materials and the presence of shrubland, grass, etc.). The human ignitions of wildfires were also noted by Portuguese authorities as the cause for large occurrences. Some were caused intentionally and others were due to carelessness in the use of fire for the preparation of agricultural fields. Parente, Pereira, Amraoui, & Tedim (2018) indicate that a high percentage of wildfires in Portugal have a human origin, whether caused by accident, negligence, or arson.

Several studies on wildfires have been conducted in this country following different approaches and goals: the causes (Pereira et al., 2006), severity and regeneration of vegetation (Maia et al., 2012), incidence (Bergonse & Bidarra, 2010; Ferreira-Leite et al., 2016; Oliveira et al., 2012), and environmental impacts (Bento-Gonçalves, Vieira, Úbeda, & Martin, 2012; Esteves et al., 2012; Meneses, 2013; Meneses & Cortez, 2015; Miranda et al., 2010; Teodoro & Duarte, 2013), among others.

The recurrence of large fires was assessed by Ferreira-Leite, Bento-Gonçalves, and Vieira (2011) for the period 1981–2010, and the results were crossed with some explanatory variables (physical and human

CONTACT Bruno M. Meneses bmeneses@campus.ul.pt Centre for Geographical Studies, Institute of Geography and Spatial Planning, Universidade de Lisboa, Rua Branca Edmée Marques, Lisboa 1600-276, Portugal

Supplemental data for this article can be accessed at <https://doi.org/10.1080/17445647.2018.1454351>

© 2018 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group on behalf of Journal of Maps

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

features). The assessment and validation of wildfire susceptibility and hazard in Portugal were also performed by some authors. For example, Verde and Zêzere (2010) used 30 years of wildfires records (1975–1994), resulting in a wildfire hazard map.

However, an in-depth assessment on wildfires in Portugal is needed, i.e. based on the knowledge of the locations where fires occur, to determine the types of LUC most affected (incidence), assess the recurrence in these locations and check whether this is consistent in consecutive periods.

The main goal of this research was to map the probability of wildfire occurrence (PWO) in mainland Portugal and the assessment of the spatial and temporal distribution of wildfires (burned areas and occurrences). The second goal was the determination of PWO by different types of LUC and to identify the LUC patterns showing greater fire incidence. The return period distribution of these events (burned areas and occurrences) was also evaluated.

2. Materials and methods

2.1. Study area

The study area is mainland Portugal (88,962.5 km²). This territory is subdivided into five NUTS II

(Nomenclature of Territorial Units for Statistics): north (23.8% of the area), centre (31.6%), Lisbon (3.6%), Alentejo (35.4%), and Algarve (5.6%).

The relief of this territory is quite irregular and is characterized by deeply incised valleys surrounded by mountains in the north and by lower, less rugged relief in the south (Figure 1(A)).

The climate is strongly influenced by the Atlantic Ocean and the Mediterranean Sea due to the transition between the Mediterranean and the Atlantic climatic conditions. The rainfall regime is characterized by high spatial and inter-seasonal variability. The mean annual precipitation (MAP) ranges from less than 500 mm in the south and northeast to more than 2000 mm in the northwest. The MAP tends to increase with increasing latitude, elevation, and proximity to the Atlantic Ocean. Summer months (June, July, and August) are particularly dry, and the rainfall is concentrated mainly in the period lasting from October to March (climatological normals from Portuguese Institute for Sea and Atmosphere, IPMA).

The LUC has a greatly contrasting spatial distribution (Figure 1(B)): forests and shrubland predominate in the centre and north, with high occurrence of eucalyptus and resinous plants (mainly *Pinus pinaster*); the largest agricultural areas are found in the south, essentially in the Alentejo region, and are characterized

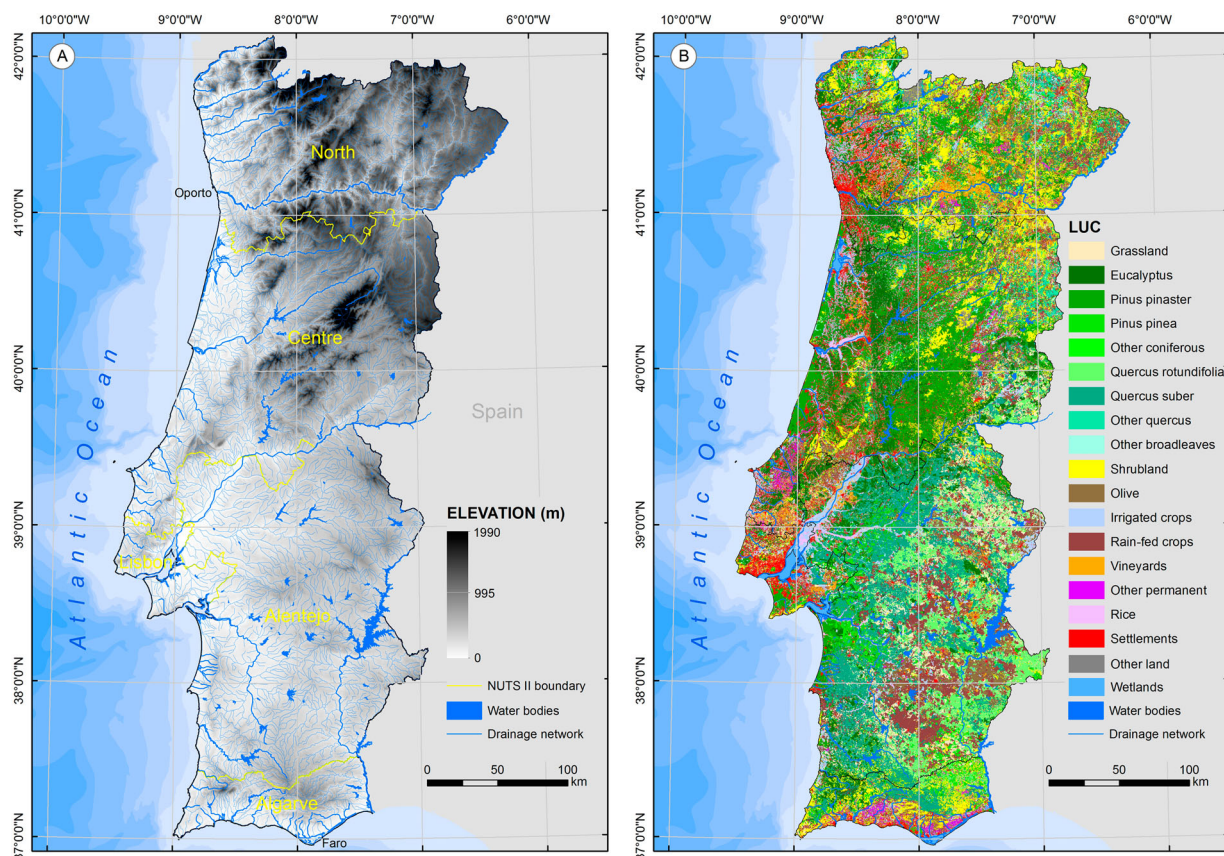


Figure 1. Mainland Portugal: (A) – elevation (data of Digital Elevation Model from the GMES RDA project, made available by the European Environment Agency); (B) –land use and land cover (LUC), 2010 (official land cover map of Portugal, provided by the General Directorate for Territorial Development, DGT).

by important extents of *Quercus* areas; and settlements predominate in the littoral areas, where the more important metropolitan areas (Lisbon and Oporto) are located.

2.2. Data

The geoinformation (GI) on burned areas (vector format, shapefile) for the study area was produced by the Institute of Agronomy (ISA-UL) (1975–1989), the Institute for the Conservation of Nature and Forest – ICNF (Portugal) (1990–2016) and the European Forest Fire Information System (EFFIS) (first half of 2017). The time series used in the wild-fires map production (1975–2016 and first semester of 2017) is the compilation of all data available by the institutions mentioned above. The ICNF data were created from EFFIS data (obtained by remote sensing) and the visual interpretation of orthophotos. The previous process was also used by ISA-UL, which completed analyses of Landsat MSS (1975–1983) and TM/ETM+ (1984–2009) satellite images. The minimum mapping unit for these data is 1 ha. Each polygon that delimits a burned area represents an occurrence, independently of the causes of the ignition (propagation, human or natural ignition, etc.). Therefore, the total occurrences in each year are represented by the number of polygons represented in this year independent of whether a wildfire was caused or influenced by other wildfires that occurred in the region.

The LUC GI (Carta de Ocupação do Solo - COS in Portuguese; or Portuguese Land Cover Map in English) is available in the General Directorate for Territorial Development (DGT) website for the years 1995, 2007, and 2010 and has the following characteristics: scale 1/25,000; minimum mapping unit of 1 ha; vector data model (polygons); and a 20-m minimum distance between lines. The cartographic information of 2007 was obtained from the photointerpretation of orthophotos (resolution of 0.5×0.5 m), a process aided by IRS (Indian remote sensing) and AWiFS (advanced wide field scanner) satellite imagery and geographic information of cadastral surveys (agriculture and forestry) performed at DGT. All results were validated (geometrically and thematically) by the DGT to obtain data with high accuracy and quality (IGP, 2010). To produce the LUC cartography of 2010, DGT used the same methodology used for the cartography of 2007. The LUC cartography of 1995, also produced by DGT, was obtained using the vectorial data of LUC boundaries of 2007 that were updated to the 1995 LUC based on orthophotos and satellite images of this year (1995). The LUC cartography for the year 1995 is only available with the nomenclature used in the Kyoto report (DGT, 2014). For this reason,

and to allow LUC comparison between different periods, the legend of the LUC maps of 2007 and 2010 follows the nomenclature used in the Kyoto report.

The production of the various maps also used complementary GI from the Portuguese Environmental Agency (elevation, drainage network and water bodies) and from the Portuguese Hydrographic Institute (bathymetry and digital terrain model of West of Iberian Peninsula Oceanic region – hydrographic zero).

2.3. Methodology

Commercial GIS software was used to perform the spatial analysis of wildfire distributions and to determine the recurrence of these events (burned area). Later, all the GI integrated in the PWO model was converted to raster (25×25 m).

In the production of the PWO map (Main Map), each annual event (individual layers) was assigned the value ‘1’ (burned area) in the reclassification of the GI. The PWO was obtained by the superposition of all layers by adding all the burned areas for the total period (Equation (1)). A lower PWO indicates that an area is affected by at least 1 wildfire in the time series (T) of burned areas and increases to the highest PWO (areas most affected by wildfires).

$$PWO = \frac{\sum_{i=1}^n Ba}{T} \quad (1)$$

where PWO represents the probability of wildfire occurrence, Ba the occurrences with burned area in each year and T the total period (years).

PWO was represented in quintiles in order to allow the user to easily understand the visible PWO, i.e. which regions are most affected by wildfires (the places with greater PWO). The colors used in the legend for the probability vary between light yellow (1) and red (5), highlighting the places where great care should be taken (preventive and reactive intervention) concerning the occurrence of wildfires.

The PWO was crossed with LUC GI (Figure 2) to identify the affected LUC patterns. This process was complemented by crossing the LUC available (1995, 2007, and 2010) by different periods of burned areas (total number of occurrences): 1995–2006 wildfire occurrences (WO) and LUC 1995; 2007–2009 WO and LUC 2007; 2010–2017 WO and LUC 2010. These procedures are important to identifying the LUC patterns that are more affected by the wildfires.

The Weibull probability distribution function was applied to calculate the return period for the forest fire occurrences (1975–2017, the first half of 2017, in mainland Portugal) and total burned area.

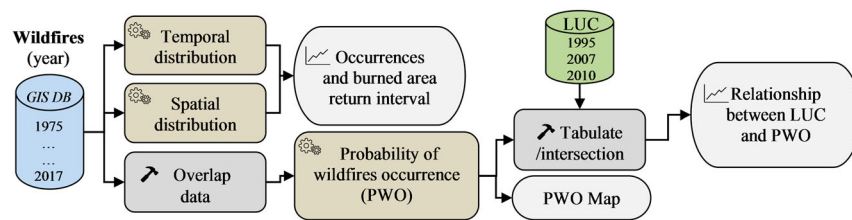


Figure 2. Methodological scheme.

3. Results analysis

3.1. Wildfires in mainland Portugal

The occurrence of wildfires in mainland Portugal varied considerably in the period 1975–2017 (first half of 2017). However, in the past few years (especially 2010–2013) (Figure 3) there was an increase in the number of fires. In general, an increase in the number of occurrences was observed, but the total burned area per year does not follow this trend. In fact, the series for the years of 2003 and 2005 shows the largest burned area (440386 and 336594 ha, respectively).

The wildfires occurred mainly in the centre and north regions of Portugal (Figure 4), where the main forest areas (pinewoods, eucalyptus, and *Quercus*) are present. However, the extent of burned areas is increasing in the past decades, in the center of Portugal, for example, the wildfires that occurred at 17 and 18 June 2017 (more than 40000 ha), which resulted in 64 dead people according to the Portuguese National Civil Protection Authority.

In the Main Map the value range goes from 0.01 to 0.41; the values were classified using quintiles, resulting in the next classes: very high (0.13–0.41), high

(0.08–0.12), medium (0.06–0.07), low (0.03–0.05), and very low (0.01–0.02).

The incidence of wildfires in this territory is very high, with areas that burned 17 times in the past 41.5 years that correspond to the areas with high PWO (Main Map). The middle sector of the centre region stands out by the extent of burned areas and the high values of PWO. These areas are especially in the Zêzere watershed, where the important surface freshwater reservoirs of Cabril and Castelo de Bode dams are located. The forest of this watershed is predominantly resinous; hence the easy spread of wildfires and the difficulty of extinguishing these fires (also because of the rough relief), resulting in large extents of burned area. Currently, the forest of this watershed is composed mainly by scrub and/or herbaceous vegetation associations, pastures, and other tree species (Meneses, Reis, Vale, & Reis, 2016), being the result of not only the burned areas' extent but also of the incidence of these events and not allowing forest regeneration, particularly of coniferous species.

The location of burned areas was influenced by the location of certain types of forests. The north and centre regions present a greater tendency for the

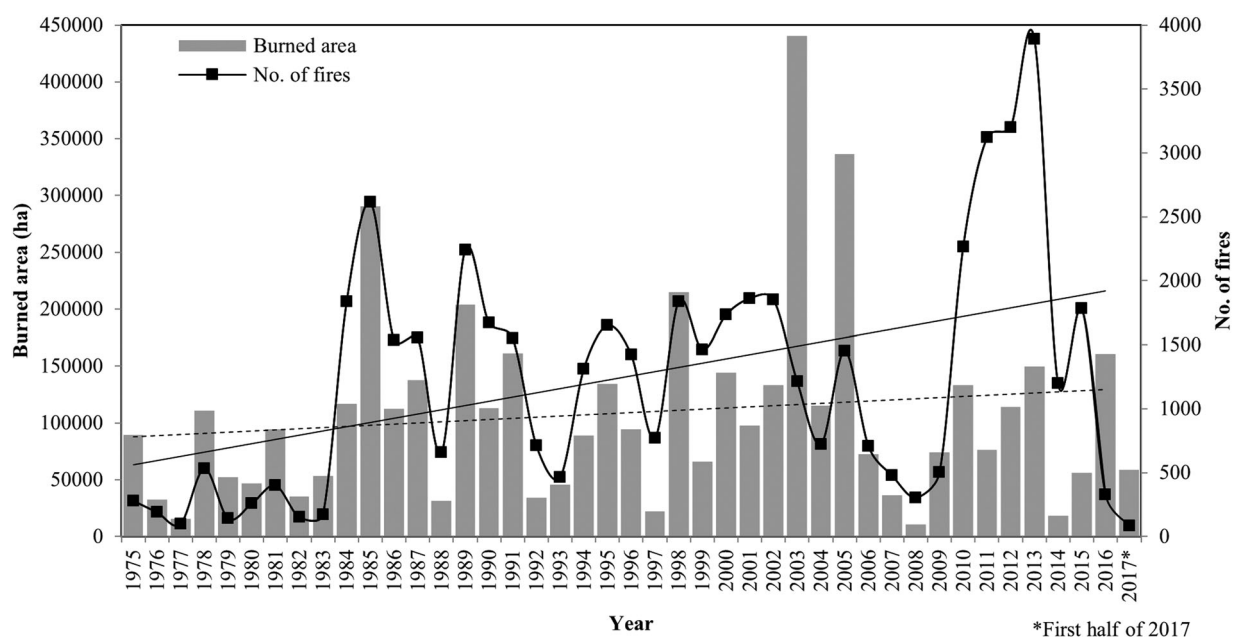


Figure 3. Burned area and number of wildfires (1975–2017) in mainland Portugal (straight lines represent the linear trend for burned area (dashed) and for No. of fires (solid) 1975–2016).

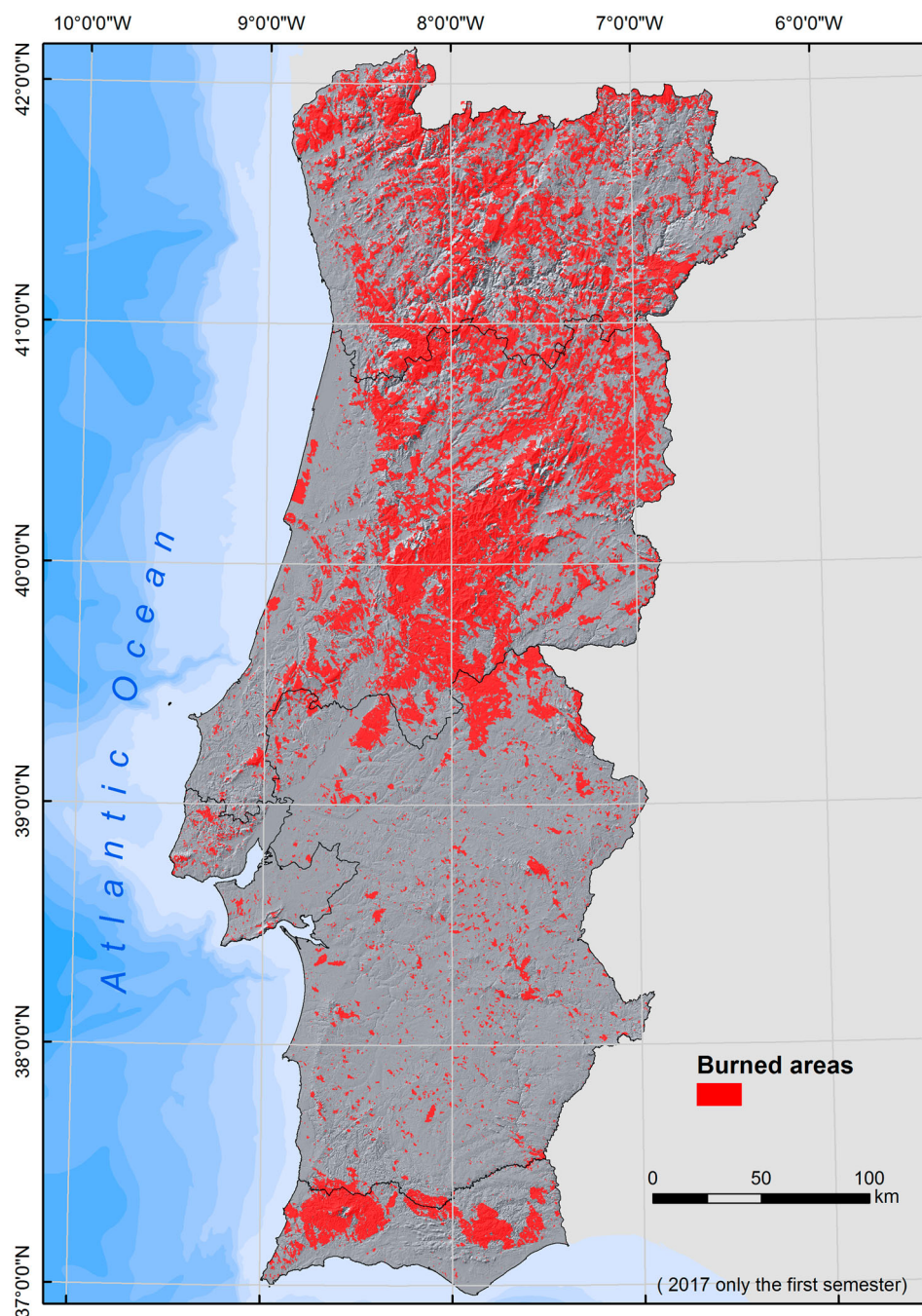


Figure 4. Burned areas in mainland Portugal resulting from wildfires from 1975 to 2017 (data of ICNF, EFFIS and ISA).

occurrence of several fires mainly due to the presence of large forest patches (pinewoods and eucalyptus). However, the north region exhibits the greatest total area burned by a factor of at least 17 (Table 1). We should also note that these two regions (north and centre) present values very close to those observed in general (Portugal) for the burned areas registered in different times (occurrences) (Table 1).

Approximately 27% of the area of mainland Portugal was affected by wildfires from 1975 to the first half of 2017, including 14.6% of this territory that burned only one time, i.e. 54.5% of the total burned area (Table 2). The percentage of burned area reduces with the number of occurrences, and this percentage

reduces greatly if an area is affected by fire more than five times (<1% of total area).

The burned area is also very variable when the regions are compared. The north and centre present more occurrences compared to other regions, and the burned area is very high for the first occurrences (i.e. in first years). The Algarve region presents a distinct case with few occurrences of fire in the same area, but the total burned area is high as a result of the large size of each occurrence.

The return intervals of the wildfire occurrences (Ori) and burned area (Bri) are different, especially between the first year in which occurred wildfires to the next years, with a highlight on the natural break

Table 1. Burned areas (%) in mainland Portugal and NUTS II, according to the number of times that the areas burned (1975–2017, first half of 2017).

	Portugal	NUTS II (total area by each NUTS)				
		North	Centre	Lisbon	Alentejo	Algarve
Total area burned at least one time	100	100	100	100	100	100
Area burned one time	65.74	70.26	65.66	55.71	52.68	55.75
Total area burned at least two times	47.05	57.99	48.14	20.24	10.18	21.37
Area burned two times	31.47	40.52	31.31	11.42	5.36	11.49
Total area burned at least three times	23.64	33.40	22.22	4.68	1.02	3.00
Area burned three times	15.89	23.07	14.49	2.60	0.535	1.62
Total area burned at least four times	12.085	18.67	10.21	0.926	0.085	0.422
Area burned four times	8.14	12.74	6.75	0.526	0.045	0.238
Total area burned at least five times	6.24	10.07	4.91	0.225	0.010	0.104
Area burned five times	4.20	6.81	3.29	0.126	0.0047	0.054
Total area burned at least six times	3.23	5.28	2.49	0.054	0	0.0052
Area burned six times	2.17	3.55	1.67	0.027	0	0.0026
Total area burned at least seven times	1.67	2.73	1.28	0	0	0.0001
Area burned seven times	1.11	1.82	0.851	0	0	0
Total area burned at least eight times	0.841	1.38	0.645	0	0	0
Area burned eight times	0.552	0.911	0.420	0	0	0
Total area burned at least nine times	0.406	0.672	0.307	0	0	0
Area burned nine times	0.263	0.440	0.195	0	0	0
Total area burned at least ten times	0.188	0.319	0.136	0	0	0
Area burned ten times	0.120	0.208	0.083	0	0	0
Total area burned at least eleven times	0.083	0.151	0.051	0	0	0
Area burned eleven times	0.052	0.097	0.030	0	0	0
Total area burned at least twelve times	0.033	0.065	0.016	0	0	0
Area burned twelve times	0.021	0.043	0.0087	0	0	0
Total area burned at least thirteen times	0.014	0.031	0.0036	0	0	0
Area burned thirteen times	0.0089	0.020	0.0020	0	0	0
Total area burned at least fourteen times	0.0065	0.020	0.0008	0	0	0
Area burned fourteen times	0.0039	0.0094	0.0004	0	0	0
Total area burned at least fifteen times	0.0023	0.0056	0.0001	0	0	0
Area burned fifteen times	0.0013	0.0034	0	0	0	0
Total area burned at least sixteen times	0.0007	0.0019	0	0	0	0
Area burned sixteen times	0.0004	0.0011	0	0	0	0
Total area burned at least seventeen times	0.0003	0.0007	0	0	0	0
Area burned seventeen times	0.0001	0.0003	0	0	0	0

of Ori (Figure 5). The probability that the determined number of occurrences is exceeded is very high for short return periods (Figure 5, graph in the right). For example, at the end of the first year, there is an approximately 50% probability of exceeding the expected number of occurrences and burned area (86 occurrences and 10573 ha, respectively). However, increases in Ori are different compared to the increase in Bri after the first years, and there is a higher Ori, resulting in large return periods.

The occurrence of extreme fires, especially considering the extent of burned area, has higher return periods, which could be favorable for the regeneration of natural vegetation in these areas. On the other hand, the higher the productivity of plants (biomass) and the greater accumulation of forest fuel facilitate an increase of fire consequences depending on the severity and intensity of these events (Fernandes & Rego, 2010).

4. Discussions

4.1. Framework of wildfires

Wildfires are recurrent events in mainland Portugal. This fact is mentioned by several authors (Ferreira-Leite et al., 2011; Ferreira-Leite et al., 2016; Oliveira et al., 2012; Verde & Zêzere, 2010) and confirmed in this research. For annual data, the number of

occurrences does not have strong correlation with the burned area. In the most recent years, more wildfires occur each year, but the total burned area is reduced. However, large wildfires have occurred, for example, the fires in 2003 that resulted in large burned areas (Montiel-Molina, 2013), and these areas are the most significant in the center of Portugal, principally in the Zêzere watershed, and have serious environment implications (Meneses, Reis, Vale, & Saraiva, 2015). The wildfires are not distributed uniformly throughout the study area. This fact was also observed by Nunes, Lourenço, & Meira (2016) both in terms of ignition density and burned area.

The incidence of wildfires may be a factor that explains the perturbation of water quality parameters (WQP), mainly for certain physicochemical elements and compounds derived from wildfires in shallow water, providing the increase in the levels of specific WQP, a fact verified by Meneses, Reis, Vale, and Saraiva (2015). The subsequent burning of the forest material in short periods does not allow for normal forest regeneration, especially for coniferous forest (Pérez-Cabello & Ibarra Benlloch, 2003). However, the occurrence of the next wildfires in the same area, due to lower available biomass, results in a smaller concentration of the elements and compounds deposited in the surface of soils (e.g. ash content post-fire), and this factor can explain the reduction in the levels of determined WQP

Table 2. Relation of the burned areas (%) in mainland Portugal and NUTS II according to the number of occurrences and total burned area (1975–2017).

	NUTS II											
	Portugal		North		Centre		Lisbon		Alentejo		Algarve	
	Burned area/ Total area	Burned area/ Total burned area	Burned area/ Total area	Burned area/ Total burned area	Burned area/ Total area	Burned area/ Total burned area	Burned area/ Total area	Burned area/ Total burned area	Burned area/ Total area	Burned area/ Total burned area	Burned area/ Total area	Burned area/ Total burned area
Area burned one time	14.62	54.53	15.85	41.29	19.83	51.01	6.40	80.09	8.65	89.80	22.48	77.68
Area burned two times	6.13	22.86	9.20	23.97	10.29	26.47	1.22	15.22	0.88	9.16	5.56	19.20
Area burned three times	2.98	11.11	5.68	14.79	4.84	12.45	0.30	3.79	0.09	0.95	0.78	2.70
Area burned four times	1.49	5.57	3.44	8.97	2.08	5.35	0.05	0.68	0.01	0.07	0.09	0.30
Area burned five times	0.76	2.85	1.98	5.16	0.90	2.33	0.01	0.16	0.001	0.01	0.03	0.11
Area burned six times	0.39	1.46	1.05	2.74	0.44	1.13	0.005	0.06	0	0	0.002	0.006
Area burned seven times	0.21	0.78	0.57	1.48	0.23	0.60	0	0	0	0	0	0
Area burned eight times	0.11	0.43	0.31	0.80	0.13	0.33	0	0	0	0	0	0
Area burned nine times	0.06	0.22	0.16	0.41	0.07	0.17	0	0	0	0	0	0
Area burned ten times	0.03	0.11	0.07	0.19	0.04	0.09	0	0	0	0	0	0
Area burned eleven times	0.02	0.06	0.04	0.11	0.02	0.04	0	0	0	0	0	0
Area burned twelve times	0.01	0.02	0.01	0.04	0.01	0.02	0	0	0	0	0	0
Area burned thirteen times	0.002	0.01	0.01	0.02	0.001	0.003	0	0	0	0	0	0
Area burned fourteen times	0.001	0.005	0.005	0.01	0	0.001	0	0	0	0	0	0
Area burned fifteen times	0.0005	0.002	0.002	0.01	0	0	0	0	0	0	0	0
Area burned sixteen times	0.0001	0.001	0.001	0.002	0	0	0	0	0	0	0	0
Area burned seventeen times	0.0001	0	0	0.001	0	0	0	0	0	0	0	0
Total burned area	26.81	100	38.38	100	38.88	100	7.99	100	9.63	100	28.94	100
Area not burned	73.19		61.62		61.12		92.01		90.37		71.06	

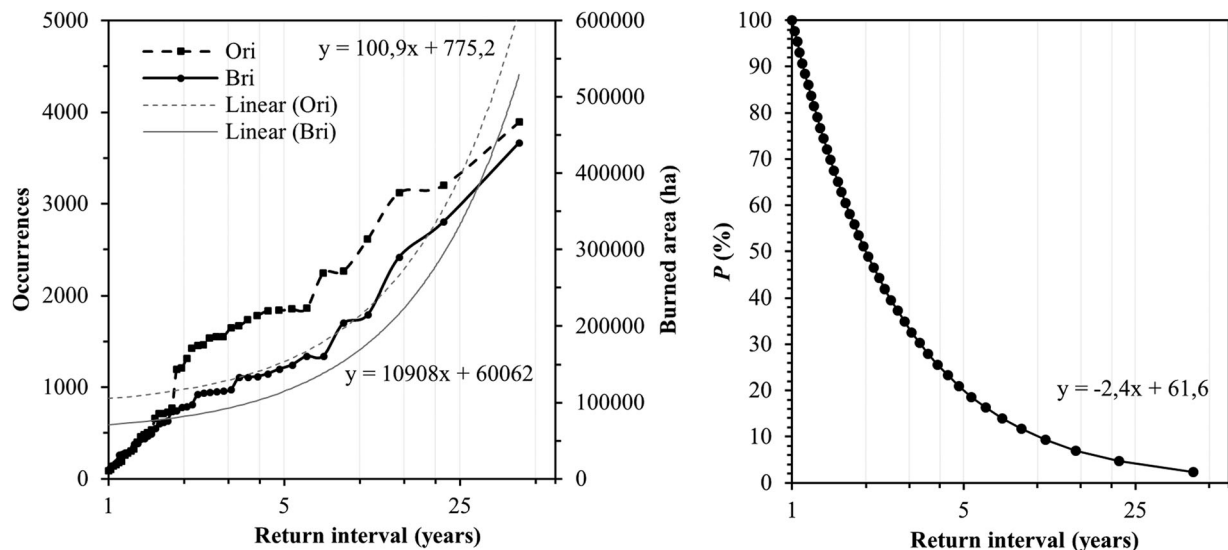


Figure 5. Wildfire occurrences (Ori) and burned area (Bri) return interval (left) and the probability (P) of the determined number occurrences and burned area to be exceeded (right), in mainland Portugal.

in the main superficial freshwater reservoirs (Meneses et al., 2015; Shin, Sidharthan, & Shin Young, 2002; Vila-Escalé, Vegas-Vilarrúbia, & Prat, 2007).

Other negative consequences were the impacts of wildfires on human life (Finlay, Moffat, Gazzard, Baker, & Murray, 2012; Fowler, 2003), and Portugal stands out in the international context for the number of deaths year after year. The year 2017 stands out in this report, with 64 deaths in a fire in the centre region. The loss of forest also influences the biotic diversity, induces ecological perturbations, reduces employment (directly or indirectly linked to the forest), and causes socio-economic difficulties for the affected populations, among other consequences. The maps of burned areas and PWO are important to evaluate these consequences and for the creation of preventive and reactive measures.

4.2. Relation between LUC and wildfires

Wildfires occur most frequently in shrubland areas, eucalyptus, and *Pinus pinaster* forests (Table 3), but the incidence of wildfires in the areas with these LUC types is very variable between different periods. However, the PWO is very high in shrubland areas compared to other LUC types, and this result agrees with the high frequency of burned area presented in Table 3. The results obtained reflect also the fast regeneration of this type of vegetation in the burned areas and the creation of new conditions that facilitate the next wildfires due to the biomass availability.

The eucalyptus forest is noted by several authors as being very prone to large wildfires (Catry, Moreira, Tujeira, & Silva, 2013; Ferreira-Leite et al., 2016; Oliveira et al., 2012) due to the characteristics of this vegetation (pyrophytes species) and the rapid regeneration of this species (areas more favorable to the occurrence

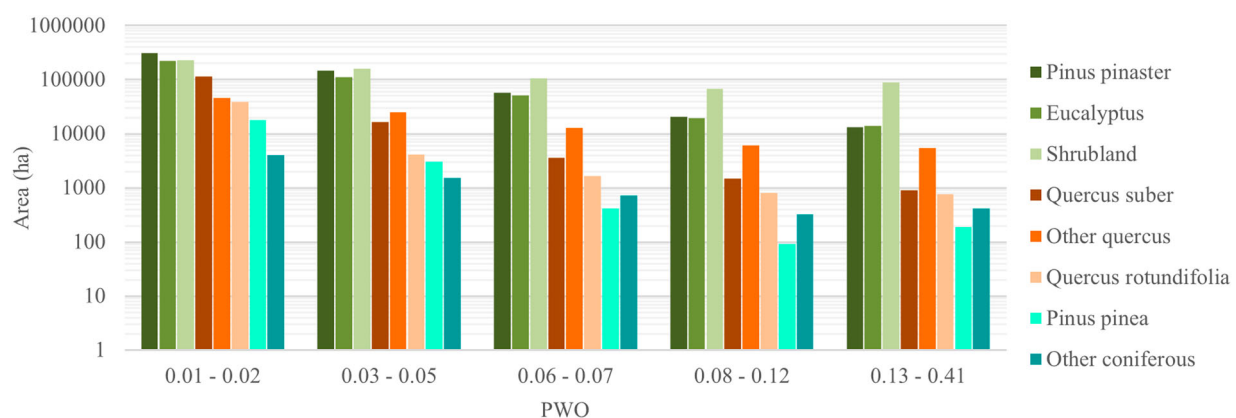
of more fires). However, the PWO of this forest type is lower compared to that of *Pinus pinaster*. On the one hand, the decrease in pine forest area in Portugal is linked to wildfires (slow regeneration after the first wildfire, but if it was affected by other wildfires in a short period, the regeneration of this species does not occur because young pines do not have seeds for the regeneration process), and this trend could be the result of fire severity or increasing fire recurrence (Lucas-Borja et al., 2016). On the other hand, the high incidence of the pinewood nematode vector in Portugal was also responsible for heavy losses of pine trees (Autoridade Florestal Nacional, 2012; Meneses et al., 2017). The incidence of this vector constitutes a large disincentive to replanting new pine forests, and after the wildfires, most landowners opt for other alternatives. This fact also explains the reduction of this type of forest in the study area.

Arnan, Quevedo, and Rodrigo (2013) indicate that changes in fire regimes can give rise to new types of forest cover or increase the distribution range of scarce forests in a regional context. This phenomenon is indirectly evidenced in this research, and we highlight the fact that the burned areas with a high incidence of wildfires have even more difficulty in regenerating forests, especially pine forests, when those affected by fires are later occupied essentially by shrubland. This LUC (in the Portuguese territory) was quantified in recent research presented by Meneses, Reis, Vale, and Reis (2018). This fact explains the extensive burned area and high PWO observed in this LUC type at different times.

In general, the *Quercus* forest exhibits reduced burned area compared to shrubland, *Pinus pinaster*, and eucalyptus forest, and the PWO is also lower in this type of LUC (Figure 6). This type of vegetation is more resistant to fire (Curt, Bertrand, Borgniet,

Table 3. LUC and the number of wildfire occurrences (% burned area) in mainland Portugal.

LUC Type	LUC 1995							LUC 2007			LUC 2010				
	1st occur.	2nd occur.	3rd occur.	4th occur.	5th occur.	6th occur.	7th occur.	1st occur.	2nd occur.	3rd occur.	1st occur.	2nd occur.	3rd occur.	4th occur.	5th occur.
Grassland	2.93	0.46	0.13	0.04	0.00	0	0	3.97	0.09	0	2.06	0.18	0.01	0.001	0
Shrubland	22.95	7.26	1.92	0.55	0.09	0.008	0.001	41.20	1.11	0.001	28.34	5.47	0.83	0.03	0.001
<i>Eucalyptus globulus</i>	11.99	1.92	0.25	0.04	0.01	0	0	6.31	0.03	0	17.01	1.27	0.14	0	0
<i>Pinus pinaster</i>	20.54	2.90	0.38	0.07	0.01	0.001	0	15.22	0.27	0	19.25	1.74	0.13	0.001	0
<i>Pinus pinea</i>	0.49	0.02	0.00	0	0	0	0	0.47	0.003	0	0.66	0.02	0.001	0	0
Other coniferous	0.06	0.01	0.00	0.001	0.001	0	0	0.25	0.001	0	0.17	0.02	0.003	0	0
<i>Quercus rotundifolia</i>	1.58	0.09	0.02	0.001	0	0	0	2.51	0.05	0	0.74	0.06	0.001	0	0
<i>Quercus suber</i>	5.96	0.32	0.02	0.003	0.002	0	0	1.58	0.02	0	3.24	0.05	0.002	0	0
Other <i>Quercus</i>	2.43	0.60	0.12	0.02	0.003	0	0	6.78	0.10	0	4.11	0.37	0.03	0.001	0
Irrigated crops	0.51	0.04	0.01	0.001	0	0	0	1.12	0.001	0	0.91	0.04	0.00	0	0
Olive	1.82	0.09	0.01	0	0	0	0	1.01	0.001	0	1.28	0.03	0.001	0	0
Other broadleaves	1.84	0.30	0.05	0.01575	0.00342	0	0	6.56	0.43	0	3.60	0.25	0.02	0	0
Rain-fed crops	4.23	0.37	0.05	0.00627	0	0	0	5.37	0.04	0	3.76	0.19	0.01	0	0
Rice	0.02	0	0	0	0	0	0	0.04	0	0	0	0	0	0	0
Vineyards	0.28	0.01739	0.002	0	0	0	0	0.29	0.001	0	0.45	0.02	0	0	0
Other land	2.14	0.88	0.29	0.09	0.02	0.002	0	4.00	0.14	0	1.95	0.28	0.03206	0.001	0
Other permanent	0.19	0.00861	0.001	0	0	0	0	0.23	0.001	0	0.18	0.00	0	0	0
Settlements	0.32	0.01814	0.002	0	0	0	0	0.45	0.02	0	0.74	0.03	0	0	0
Wetlands	0.19	0.00596	0	0	0	0	0	0.32	0.000	0	0.26	0.00	0	0	0

**Figure 6.** Distribution of forest classes area (COS 2010) in mainland Portugal by the classes of PWO (represented in quintiles).

Ferrieux, & Marini, 2010), and this factor can explain the low burned area observed in *Quercus rotundifolia*, *Quercus suber* and other *Quercus* areas (Table 3) compared to the types of forest mentioned before. Evidently, these LUC types exhibit lower PWO, explained by a low incidence of fires in this type of forest.

Some agricultural areas also exhibit burned areas, which can be caused by the propagation of wildfires or by locals starting fires (due to uncontrolled burnings) and consequent propagation to the forest, but the fire incidence in these areas is low (anthropic management activities) (Table 3).

5. Conclusions

Portugal has a history of catastrophic wildfires. Those more affected are the centre and north regions, but these regions also presented the highest percentage of forested area. The incidence of wildfires is most significant in the centre (Main Map), where the largest wildfires also occurred in the past years.

The return period of wildfires with the reduced burned area is very low in mainland Portugal; however, there is a high probability of many occurrences of small-magnitude fires in relatively short periods.

Pinus pinaster and *Eucalyptus globulus* presented high PWO, but shrubland stands out for the highest area burned and highest PWO. This fact is explained by the regeneration of this vegetation type in burned areas and its predominance in the Portuguese territory.

The PWO map (Main Map) is important in identifying the places most affected by these events and identifying where the next wildfires can occur based on the probability calculated from the incidents recorded in the past. This map also provides support for the creation of broad guidelines for economic and territorial policies, especially for the planning and management of forests and other natural resources. This map also allows for new approaches to fire probability studies in mainland Portugal and will allow for the validation of future fire risk maps produced by different institutions.

The data and procedures used in this paper possess two characteristics that may in some way influence the results and that should be taken into account in future research. First, the relatively long periods of the 1995–2006 and 2010–2017 series do not provide any assurance that the various land cover classes present in the reference cartography are maintained throughout these series. Since it is not possible to obtain other

dates for land cover cartography at this stage, one possibility is to use a shorter period of burned area data after each land cover date in order to reduce this possible discrepancy. Second, in the areas burned in each year, there is a change in the land cover; so new wildfires will affect a different class compared to those present in the reference land cover cartography. One possible way to overcome this situation is to update each year with the burned areas mapped in the previous year so that each land cover class is replaced an 'area burned in the previous year' class.

Software

ESRI ArcGIS 10.5 was used to evaluate the wildfire distributions, model the PWO, and design the maps.




Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

Bruno Meneses was financed through a grant of the Institute of Geography and Spatial Planning and Universidade de Lisboa, IGOT-UL [BD2015].

ORCID

Bruno M. Meneses  <http://orcid.org/0000-0003-3348-6732>
Eusébio Reis  <http://orcid.org/0000-0001-8367-1835>
Rui Reis  <http://orcid.org/0000-0001-8212-5111>

References

- Annan, X., Quevedo, L., & Rodrigo, A. (2013). Forest fire occurrence increases the distribution of a scarce forest type in the Mediterranean Basin. *Acta Oecologica*, 46, 39–47. doi:10.1016/j.actao.2012.10.005
- Autoridade Florestal Nacional. (2012). *Nemátodo da madeira do pinheiro – Atividades realizadas no âmbito do seu controlo*. Lisboa, Portugal.
- Bento-Gonçalves, A., Vieira, A., Úbeda, X., & Martin, D. (2012). Fire and soils: Key concepts and recent advances. *Geoderma*, 191, 3–13. doi:10.1016/j.geoderma.2012.01.004
- Bergonse, R. V., & Bidarra, J. M. (2010). Probabilidade Bayesiana e Regressão Logística na Avaliação da Susceptibilidade de Ocorrência de Incêndios de Grande Magnitude. *Finisterra*, 45(89), 79–104.
- Catry, F. X., Moreira, F., Tujeira, R., & Silva, J. S. (2013). Post-fire survival and regeneration of *Eucalyptus globulus* in forest plantations in Portugal. *Forest Ecology and Management*, 310, 194–203. doi:10.1016/j.foreco.2013.08.036
- Curt, T., Bertrand, R., Borgniet, L., Ferrieux, T., & Marini, E. (2010). *The impact of fire recurrence on populations of Quercus suber in southeastern France*. VI International Conference on Forest Fire Research (10 p.), Nov 2010, Coimbra, Portugal. HAL Id: hal-00583408. Retrieved from <https://hal.archives-ouvertes.fr/hal-00583408>
- DGT. (2014). *Land use and land cover evolutions in continental Portugal*. Work to support reporting of emissions and carbon sequestration in the sector use and land use changes. Kyoto Protocol and United Nations Framework Convention on Climate Changes, Lisbon.
- Esteves, T. C. J., Kirkby, M. J., Shakesby, R. A., Ferreira, A. J. D., Soares, J. A. A., Irvine, B. J., ... Carreiras, M. A. (2012). Mitigating land degradation caused by wildfire: Application of the PESERA model to fire-affected sites in central Portugal. *Geoderma*, 191, 40–50. doi:10.1016/j.geoderma.2012.01.001
- Fernandes, P., & Rego, F. (2010). Combustíveis e combustão em ambiente florestal. In F. Moreira, F. X. Catry, J. S. Silva, & F. Rego (Eds.), *Ecologia do fogo e gestão de áreas ardidas* (pp. 13–20). Lisboa: ISAPress.
- Ferreira-Leite, F., Bento-Gonçalves, A., & Vieira, A. (2011). The recurrence interval of forest fires in Cabeço da Vaca (Cabreira Mountain-northwest of Portugal). *Environmental Research*, 111(2), 215–221. doi:10.1016/j.envres.2010.05.007
- Ferreira-Leite, F., Bento-Gonçalves, A., Vieira, A., Nunes, A., & Lourenço, L. (2016). Incidence and recurrence of large forest fires in mainland Portugal. *Natural Hazards*, 84(2), 1035–1053. doi:10.1007/s11069-016-2474-y
- Finlay, S. E., Moffat, A., Gazzard, R., Baker, D., & Murray, V. (2012). Health impacts of wildfires. *PLoS Currents*, 4(2). doi:10.1371/4f959951cce2c
- Fowler, C. (2003). Human health impacts of forest fires in the Southern United States: A literature review. *Journal of Ecological Anthropology*, 7, 39–63. doi:10.5038/2162-4593.7.1.3
- Gomes, J. F. P. (2006). Forest fires in Portugal: How they happen and why they happen. *International Journal of Environmental Studies*, 63(2), 109–119. doi:10.1080/00207230500435304
- IGP. (2010). *Carta de Uso e Ocupação do Solo de Portugal Continental para 2007 (COS2007)*. *Memória descritiva* (1st ed.). Lisboa: Instituto Geográfico Português / Direção Geral do Território.
- Lucas-Borja, M. E., Ahrazem, O., Candel-Pérez, D., Moya, D., Fonseca, T., Hernández Tecles, E., ... Gómez-Gómez, L. (2016). Evaluation of fire recurrence effect on genetic diversity in maritime pine (*Pinus pinaster* Ait.) stands using inter-simple sequence repeat profiles. *Science of the Total Environment*, 572, 1322–1328. doi:10.1016/j.scitotenv.2016.01.105
- Maia, P., Pausas, J. G., Vasques, A., & Keizer, J. J. (2012). Fire severity as a key factor in post-fire regeneration of *Pinus pinaster* (Ait.) in Central Portugal. *Annals of Forest Science*, 69(4), 489–498. doi:10.1007/s13595-012-0203-6
- Meneses, B. M. (2013). The Impact of forest fires on soil loss from water erosion in Serra de Santa Helena [in portuguese]. *Revista Geográfica de América Central*, 51, 215–232.
- Meneses, B. M., & Cortez, N. (2015). Effect of a forest fire on physicochemical properties of the water of São Domingos Stream (Western Region of Portugal) [in portuguese]. *Journal of Waters Resources*, 36(1), 1–10.
- Meneses, B. M., Reis, E., Pereira, S., Vale, M., & Reis, R. (2017). Understanding driving forces and implications associated with the land use and land cover changes in Portugal. *Sustainability*, 9(3), 351. doi:10.3390/su9030351
- Meneses, B. M., Reis, E., Vale, M. J., & Reis, R. (2016). Urban sprawl in Zêzere watershed (Portugal) and the risk of reduction of the water quality. In P. T. Costa, D. Quino, & R. A. C. Garcia (Eds.), *ICUR2016 proceedings: International conference on urban risks* (pp. 819–826). Lisboa: CERU – European Centre on Urban Risks. Retrieved from http://www.ceru-europa.pt/icur2016/ICUR2016_Proceedings.pdf

- Meneses, B. M., Reis, E., Vale, M. J., & Reis, R. (2018). Modeling land use and land cover changes in Portugal: A multi-scale and multi-temporal approach. *Finisterra*, *LIII*(107), 3–26. doi:10.18055/Finis12258
- Meneses, B. M., Reis, R., Vale, M. J., & Saraiva, R. (2015). Land use and land cover changes in Zêzere watershed (Portugal) – Water quality implications. *Science of the Total Environment*, 527–528, 439–447. doi:10.1016/j.scitotenv.2015.04.092
- Miranda, A. I., Martins, V., Schaap, M., San José, R., Perez, J. L., Monteiro, A., ... Sá, E. (2010). Numerical modelling of 2003 summer forest fires impacts on air quality over Portugal. In G. Perona & C. A. Brebbia (Eds.), *Modelling, monitoring and management of forest fires II* (137th ed., pp. 71–82). Boston: WITpress.
- Montiel-Molina, C. (2013). Comparative assessment of wildland fire legislation and policies in the European Union: Towards a fire framework directive. *Forest Policy and Economics*, 29, 1–6. doi:10.1016/j.forpol.2012.11.006
- Nunes, A. N., Lourenço, L., & Meira, A. C. C. (2016). Exploring spatial patterns and drivers of forest fires in Portugal (1980–2014). *Science of the Total Environment*, 573, 1190–1202. doi:10.1016/j.scitotenv.2016.03.121
- Oliveira, S. L. J., Pereira, J. M. C., & Carreiras, J. M. B. (2012). Fire frequency analysis in Portugal (1975–2005), using Landsat-based burnt area maps. *International Journal of Wildland Fire*, 21(1), 48–60. doi:10.1071/WF10131
- Parente, J., Pereira, M. G., Amraoui, M., & Tedim, F. (2018). Negligent and intentional fires in Portugal: Spatial distribution characterization. *Science of The Total Environment*, 624, 424–437. doi:10.1016/j.scitotenv.2017.12.013
- Parente, J., Pereira, M. G., & Tonini, M. (2016). Space-time clustering analysis of wildfires: The influence of dataset characteristics, fire prevention policy decisions, weather and climate. *Science of the Total Environment*, 559, 151–165. doi:10.1016/j.scitotenv.2016.03.129
- Pereira, J. S., Pereira, J. M. C., Rego, F. C., Silva, J. M. N., & Silva, T. P. (2006). *Incêndios florestais em Portugal: caracterização, impactes e prevenção*. (J. S. Pereira, J. M. C. Pereira, F. C. Rego, J. M. N. Silva, & T. P. da Silva, Eds., 1st ed.). Lisboa: Instituto Superior de Agronomia.
- Pérez-Cabello, F., & Ibarra Benlloch, P. (2003). Las formaciones vegetales colonizadoras de los espacios quemados prepirenaicos. *Cuadernos de Investigación Geográfica*, 29, 35–49.
- Pôças, I., Cunha, M., & Pereira, L. S. (2011). Remote sensing based indicators of changes in a mountain rural landscape of Northeast Portugal. *Applied Geography*, 31(3), 871–880. doi:10.1016/j.apgeog.2011.01.014
- Santos, T., Tenedório, J. A., Rocha, J., & Encarnação, S. (2005). SATSTAT: *Exploratory analysis of Envisat-MERIS data for land cover mapping of Portugal in 2003*. 14TH European Colloquium on Theoretical and Quantitative Geography, Portugal.
- Shin, H.-W., Sidharthan, M., & Shin Young, K. (2002). Forest fire ash impact on micro- and macroalgae in the receiving waters of the east coast of South Korea. *Marine Pollution Bulletin*, 45(1–12), 203–209. doi:10.1016/S0025-326X(02)00156-X
- Teodoro, A. C., & Duarte, L. (2013). Forest fire risk maps: A GIS open source application – a case study in Norwest of Portugal. *International Journal of Geographical Information Science*, 27(4), 699–720. doi:10.1080/13658816.2012.721554
- Verde, J. C., & Zêzere, J. L. (2010). Assessment and validation of wildfire susceptibility and hazard in Portugal. *Natural Hazards and Earth System Science*, 10(3), 485–497. doi:10.5194/nhess-10-485-2010
- Vila-Escalé, M., Vegas-Vilarrúbia, T., & Prat, N. (2007). Release of polycyclic aromatic compounds into a Mediterranean creek (Catalonia, NE Spain) after a forest fire. *Water Research*, 41(10), 2171–2179. doi:10.1016/j.watres.2006.07.029